Technical Support Document

Coal-to-Liquids Products Industry Overview

Proposed Rule for Mandatory Reporting of Greenhouse Gases

Office of Air and Radiation
U.S. Environmental Protection Agency

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1.0. Introduction

1.1. Purpose

This document provides an overview of the status of the emerging coal-to-liquids (CTL) industry both in the United States and elsewhere. The analysis here is part of a larger effort to develop guidelines for mandatory reporting requirements for greenhouse gases (GHGs). In December 2007, Congress enacted an omnibus appropriations bill that directs EPA to develop and publish a rule requiring measurement and reporting of GHG emissions above appropriate thresholds in all sectors of the economy. The bill mandates that EPA publish a proposed rule within nine months and a final rule within 18 months. Understanding the information that fuel suppliers already generate and report to federal agencies is a first step in developing mandatory GHG reporting requirements.

Since CTL is a nascent industry in which the only operational plants are overseas this document focuses more on the status of the industry, the emerging technologies, and identifies the operational plants and those that are planned.

Existing research and development (R&D) work indicates that the carbon content of the products from a CLT plant, particularly a plant using Fischer Tropsch technology, have a different and potentially lower carbon content compared to those from a conventional petroleum refinery. However, data are difficult to identify and the current approach, until further knowledge is available, is to use the petroleum default table in Subpart MM Petroleum Suppliers to calculate the carbon content of CTL derived products.

1.2. Organization of this Report

To provide context for the CTL sector, section 2 provides an overview of the industry and focuses on the two dominant technologies, the indirect Fischer Tropsch and direct liquefaction of coal. There is too a brief discussion of Mobil's methanol-to-gasoline (MTG) process. There is also some discussion of the type of products that come from a CLT plant and whether or not they need further processing. Section 3 discusses the existing plants, plants that are under construction and planned plants. Since this is a nascent industry the discussion is not confined only to the United States. Finally, Section 4 focuses on what is known about the carbon content of CTL products.

2.0. Overview of the Coal-to-Liquids Industry

Coal-to-Liquids technology has been known and used for a long time. The underlying technology, coal gasification, was developed in the 19th century, the product being "town gas" which was used for lighting and cooking. Use of town gas became widespread in both Europe and the United States. In the 1920s the Fischer-Tropsch process was developed to convert the main constituents of the gas, hydrogen and carbon monoxide to liquid fuels.

At the beginning of the 20th century the direct liquefaction process was first done by reacting coal with hydrogen and process solvent at high temperatures and pressure to produce liquid fuels. This direct liquefaction process was used to produce high octane aviation gasoline by Germany during World War II. The Fischer Tropsch technology was also used in Germany in the war. However, given the costs of the technology and the very low prices of petroleum its only use came towards the end of the Nazi regime in Germany and during the period of apartheid in South Africa. Sanctions and war cut off most petroleum to these two countries so that need rather than prices determined the use of the technology.

Although research into CTL has continued, apart from the South African plants no other plants were planned before the substantial increase in crude oil prices commencing after 2000. The substantial increase in crude oil prices, combined with concern over geopolitical instability in the major producing areas, and the increasing competition for limited resources has resulted in attention once again turning to alternative sources for transportation fuels, whether biofuels, gas to liquids, coal gasification, or coal to liquids. Oil prices, driven by burgeoning global demand have reached a high enough level that these alternative sources, despite the unprecedented increase in capital and operating costs, can be deemed economic as well as technically feasible. CTL is the subject of increasing attention as coal resources are widespread and voluminous.

Although there has been limited application of these alternative fuel sources, the front end technology of gasification has advanced considerably. Between 2000 and 2007, 27 new coal gasification facilities became operational around the world.[1] Three of these plants produce electrical power using a combination of steam and gas, and the others are used to produce synthesis gas for the manufacture of chemicals, particularly ammonia and methanol. Consequently, there have been significant advances in coal gasification.

2.1. Three Technologies

There are currently three established technologies for CTL plants: the indirect method in which coal is first gasified and then converted to liquid fuels through the process of Fischer Tropsch synthesis; the MTG process, which is a subset of the indirect method; and the direct method in which coal is directly converted to liquid fuels with the help of hydrogen and heavy oils. Exhibit 1 lists all the current component technologies for CTL.

2.1.1. Fischer-Tropsch (FT)

Exhibit 2 presents a flow diagram of the Sasol CTL process. Sasol has developed two technologies based on the Fischer Tropsch process: 1) the High Temperature Fischer Tropsch process which can be used to produce a slate of light products as well as the building blocks of high value added chemicals, and 2) the Low Temperature Fischer Tropsch process that is used for producing diesel from coal.

Exhibit 2 represents the Low Temperature process. As the exhibit shows coal is fed to gasifiers to produce raw gas which is then purified into the synthesis gas (a mixture of hydrogen and carbon monoxide) which is then fed into the Fischer

[1] The Rand Corporation, *Producing Liquid Fuels from Coal*, 2008

Tropsch synthesis and converted to heavy hydrocarbons in the presence of a catalyst.

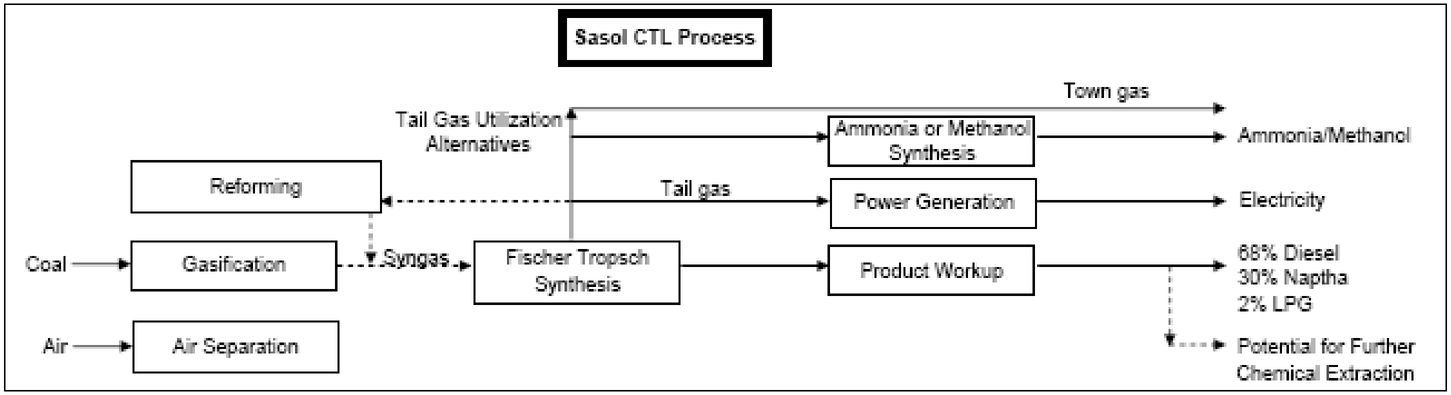
One of the advantages of the FT process is that the synthesis gas can be made from a variety of feedstocks other than coal. Commercial development over the past 20 years has centered around using various deposits of stranded gas. The resulting various Gas-to-Liquids plants all use a variation of the FT process. Considerable work has also been done examing adding biomass to the coal feedstock as a means of reducing stationary source greenhouse gas emissions.

The products can be upgraded by hydrocracking, chemical workup or by refining through a conventional petroleum refinery depending on the product slate required.

Exhibit 1: Coal Liquefaction Technologies

Mild Pyrolysis	Single-Stage Direct Liquefaction	Two-Stage Direct Liquefaction	Co-Processing and Dry Hydrogenation	Indirect Liquefaction
- Liquids from Coal (LFC) Process – Encoal	- Solvent Refined Coal Processes (SRC-I and SRC-II) – Gulf Oil	- Consol Synthetic Fuel (CSF) Process	- MITI Mark I and Mark II Co-Processing	- Sasol
- Coal Technology Corporation	- Exxon Donor Solvent (EDS) Process	- Lummus ITSL Process	- Cherry P Process – Osaka Gas Co.	- Rentech
- Univ. of North Dakota Energy and Environmental Center (EERC)/AMAX R&D Process	- H-Coal Process – HRI	- Chevron Coal Liquefaction Process (CCLP)	- Solvolysis Co-Processing – Mitsubishi	- Syntroleum
- Institute of Gas Technology	- Imhausen High-Pressure Process	- Kerr-McGee ITSL Work	- Mobil Co-Processing	- Mobil Methanol-to-Gasoline (MTG) Process
- Char, Oil Energy Development (COED)	-Conoco Zinc Chloride Process	- Mitsubishi Solvolysis Process	- Pyrosol Co-Processing – Saabergwerke	- Mobil Methanol-to-Olefins (MTO) Process
	- Kohleoel Process – Ruhrkohle	- Pyrosol Process – Saarbergwerke	- Chevron Co-Processing	- Shell Middle Distillate Synthesis (SMOS)
	- NEDO Process	- Catalytic Two-Stage Liquefaction Process – DOE and HRI	- Lummus Crest Co-Processing	
		- Liquid Solvent Extraction (LSE) Process – British Coal	- Alberta Research Council Co-Processing	
		- Brown Coal Liquefaction (BCL) Process – NEDO	- CANMET Co-Processing	
		- Amoco CC-TSL Process	- Rheinbraun Co-Processing	
		- Supercritical Gas Extraction (SGE) Process – British Coal	- TUC Co-Processing	
			- UOP Slurry-Catalysed Co-Processing	
			- HTI Co-Processing	

Exhibit 2: Coal to Liquids Flow Diagram
Fischer Tropsch Synthesis



2.1.2 Methanol to Gasoline (MTG)

The front end of a MTG plant encompassing coal gasification would be identical to that of a CTL plant. However, the coal gasification has to produce a synthesis gas with a hydrogen-to-carbon monoxide ratio suitable for methanol synthesis. Once the methanol is produced it is dehydrated to produce dimethyl ether. The latter is then converted to a mix of hydrocarbons in the presence of special catalysts. The hydrocarbon mix that results from this is very similar to that found in raw gasoline. Products from the MTG process are about 90 percent gasoline with the rest being LPG. Both products can be sold directly into the market.

Methanol is one of the major chemicals necessary for an industrialized economy. Commercial methanol is largely produced by natural gas-derived synthesis gas. There is, however, one commercial plant in the United States where methanol is produced from coal derived synthesis gas[2]. In these cases the product desired is methanol, but a commercial scale MTG plant operated in New Zealand from 1985 to 1995 and produced 14,500 barrels per day of gasoline.

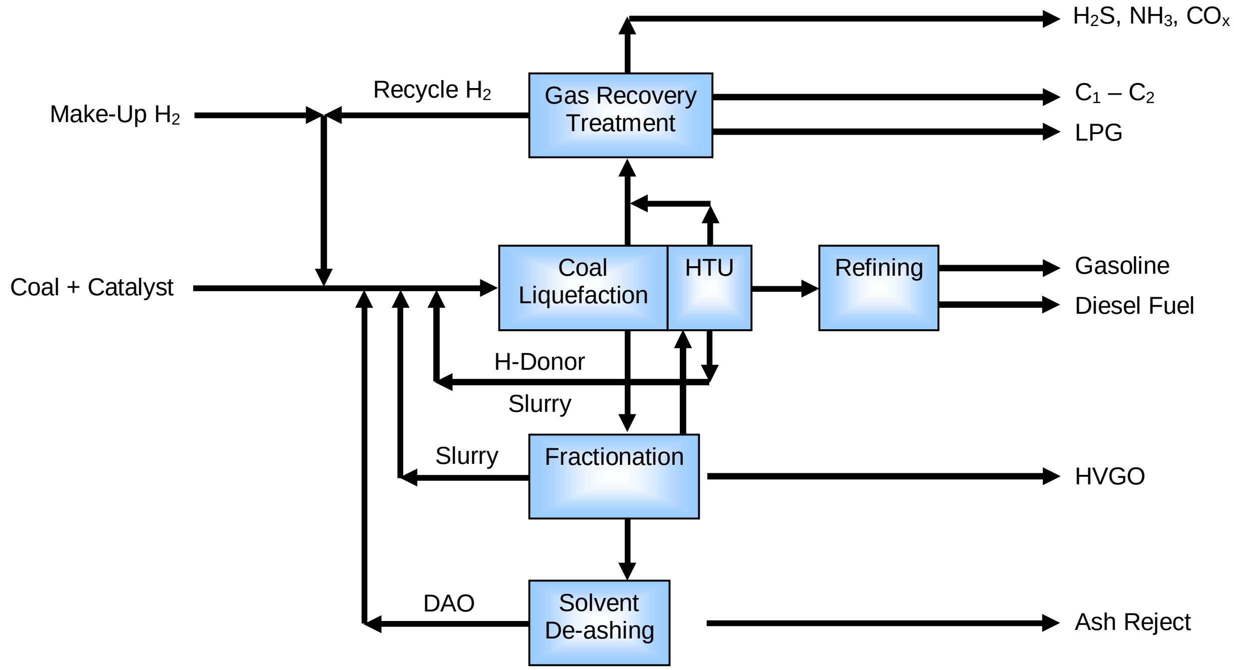
2.1.3 Direct Liquefaction

Exhibit 3 presents a flow diagram of the CTL direct liquefaction process. Under this approach coal reacts with a catalyst under high pressure and temperature in the presence of hydrogen. The products are liquid hydrocarbons and a char-like residue. This process works best using fine low-ash coal.

Compared to Fischer Tropsch synthesis direct liquefaction requires harsh process conditions (3500psi/230bar+ and 750F/400C compared to 375psi/25 bar and 400-630F/200-340C) and expensive feedstocks. In addition, more advances have been made to the Fischer Tropsch process technology and catalysts than to direct liquefaction.

[2] This plant is classified as a gasification plant.

Exhibit 3: Coal to Liquids Flow Diagram
Direct Liquefaction



2.1.4. Products

FT Products

CTL plants produce a wide range of products from gasoline to waxes. The Sasol Low Temperature process maximizes diesel fuel, while the High Temperature process maximizes gasoline. Generally speaking the focus has been to produce transportation fuels and chemical feedstocks, but naphthas and waxes are always produced irrespective of the process. Considerable work has been done in South Africa and in the United States on jet fuels for both commercial and military aircraft.

Since 1999 Sasol has supplied a mixture of CTL components and conventional kerosene to international airlines operating out of Johannesburg Airport. In April of 2008 international aviation authorities approved Sasol's fully synthetic CTL jet fuel as Jet A-1 for commercial use in all turbine aircraft. Currently ASTM is working to incorporate the synthetic jet fuel in ASTM D1655-08a *Standard Specifications for Aviation Turbine Fuels*. A blend of conventional JP8 and FT jet fuel has recently (2006) been certified for use by the U.S. Air Forces.

The synthetic jet fuel is ultra low sulphur (<5ppm) with 8% to 25% aromatics. It is fully fungible with petroleum-based jet fuel. Testing on FT jet fuel has revealed significantly reduced particulate emissions compared to conventional and military jet fuels.[3] Exhibit 4 shows the flow diagram for the manufacturing process in the High Temperature Fischer Tropsch process.

In the United States the Department of Defense has been working with Rentech to produce a new Fischer Tropsch fuel that will meet all of the agency's needs and that will be fungible with petroleum based products and thus able to use the existing infrastructure.

FT diesel fuel is very high quality. Sulfur constitutes less than 1 ppm. FT diesel has less than 1 percent aromatics and thus has a high cetane value, generally from 70 to 80. In general high cetane-number fuels reduce hydrocarbon and soot emissions from cold starts and reduce nitrogen oxide and particulate emissions from a warm engine. FT diesel can be sold as a premium product or can be blended with conventional diesel fuel to improve its qualities. Currently, there is no approved ASTM test for FT diesel, but apparently ASTM is working on a test that it is not yet ready to publish.[4]

Somewhere between 20 to 40 percent of FT products, depending on the configuration and the catalysts used, will be naphtha. FT naphtha would have to be upgraded either on site before being sent to a petrochemical plant or at a refinery.

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[3] *Ibidem*, p.22
[4] Conversation with Staff Manager for ASTM on January 28, 2009. See internal ICF Memo.

MTG products
MTG gasoline would be free of all sulfur. From what is known, MTG gasoline would be equal or superior to conventional gasoline and would have positive effects on air quality relative to benzene and Reid vapour pressure.

About 10 to 12 percent of the plant output would be LPG, mostly butane and propane. This LPG could either be sold directly into the market or to the petrochemical industry, or could be used at the plant itself to generate electricity.

Direct liquefaction products
The principal products from a coal-based direct liquefaction plant would be naphthas and middle distillates. There is considerable variation in the properties of these products, depending of course on the configuration of the plant, but unlike the products of either FT plants or MTG plants, these products cannot be sold directly in to the market place. In general direct liquefaction products contain more aromatics and cyclic hydrocarbons and they may have an overall lower hydrogen content. These products would either have to be upgraded at the plant or sent to a refinery for further upgrading.

3.0. Plants

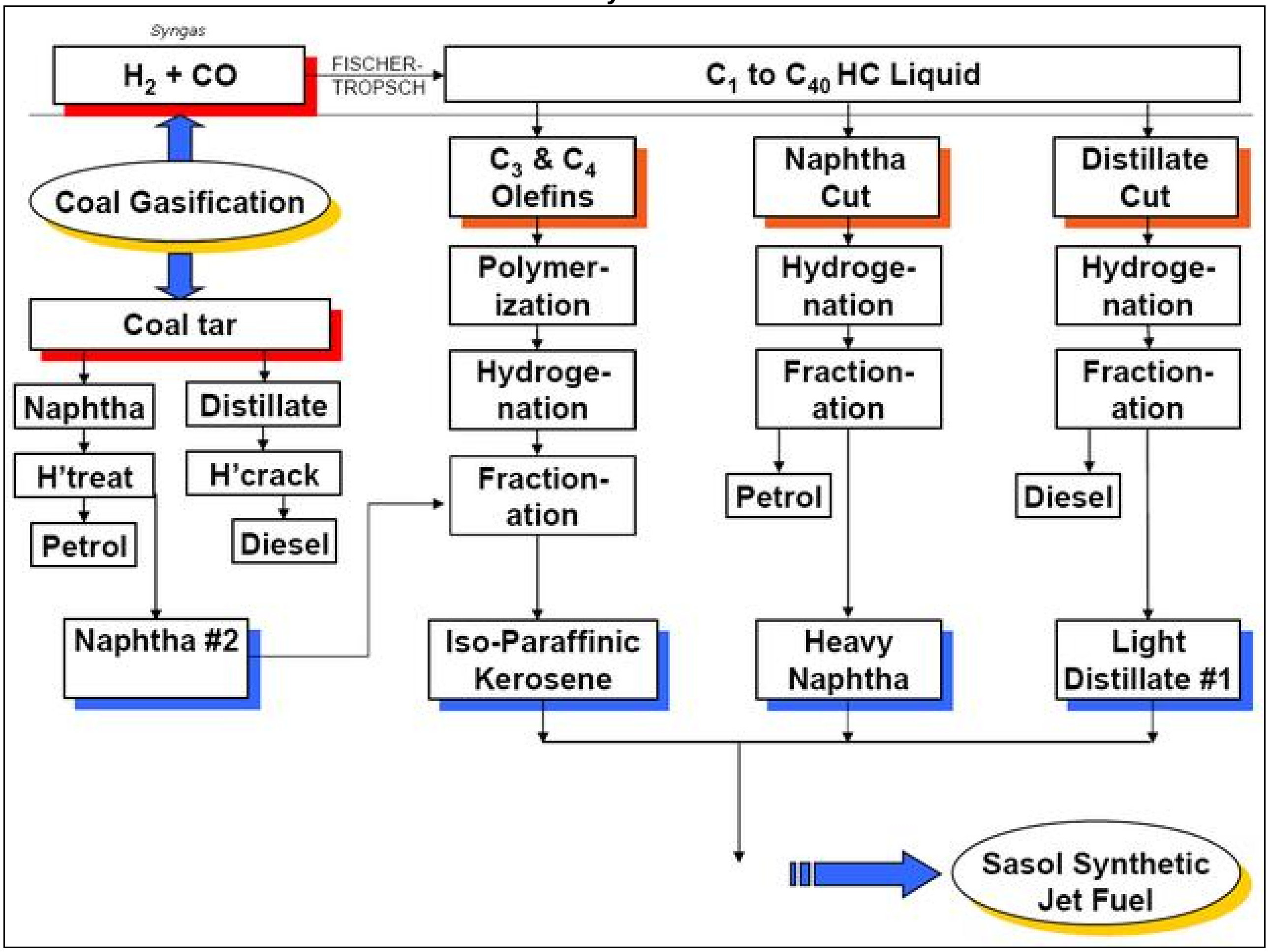
3.1. Existing Plants

Currently the only operational CTL plants are in South Africa. Sasol One, now Sasol Chemical Industries became operational in the late 1950s. Sasol Two and Three at Secunda were built in 1974 and 1978. The two plants, now combined into one, produce approximately 160,000 b/d of mostly transportation products. Both plants use the Fischer Tropsch indirect CTL technology.

Expected to come into operation in the near future is a major CTL complex at Erdos, Inner Mongolia that will be run by the Shenhua Group, China's largest coal miner. This plant, developed in conjunction with the University of West Virginia, uses direct liquefaction technology. It is expected to convert 3.5 million tonnes of coal per year into 1 million tonnes of oil products when operational, predominantly diesel for transportation.

In addition, Shenhua is working with Sasol to conduct a feasibility study to build two Fischer Tropsch CTL plants in the provinces of Shaanxi and Ningxia. Two smaller CTL plants are also under construction in China as is one in Indonesia.

Exhibit 4: Sasol CTL Synthetic Jet Fuel



3.2. Planned Plants

Currently there are fourteen CTL plants under consideration in the United States. Three are at the design stage with the others still being studied for feasibility. While most are CTL plants a number of the Rentech proposed plants will be more complex with feedstock varying from waste to biomass to petroleum coke as well as coal. Whether any will come to fruition remains to be seen.

4.0. Carbon Content of Products

There is very little hard data on the carbon content of the products of CTL plants. The literature does seem to imply that the Fischer Tropsch products will have lower CO_2 emissions when combusted. FT products contain very little aromatics which would indicate that the carbon content of FT products may be lower than that of conventional petroleum products. In testimony before the Subcommittee on Energy and Environment of the U.S. House of Representatives the following statement was made by a senior scientist from Rentech:

> *F-T fuels offer numerous benefits to aviation users. The first is an immediate reduction in particulate emissions. F-T jet fuel has been shown in laboratory combusters and engines to reduce PM emissions by 96% at idle and 78% under cruise operation. Validation of the reduction in other turbine engine emissions is still under way. Concurrent to the PM reductions is an immediate reduction in CO2 emissions from F-T fuel. F-T fuels inherently reduce CO2 emissions because they have higher energy content per carbon content of the fuel, and the fuel is less dense than conventional jet fuel allowing aircraft to fly further on the same load of fuel*.

Given that there is a dearth of hard data and that there is, as yet, no operational CTL plant in the United States, EPA is proposing that, until more data becomes available, reporters from future CTL plants use the default table in Subpart MM – Suppliers of Petroleum Products of the rule.

A number of CTL products may be sent to refineries for further upgrading, especially those products from direct liquefaction plants. Given that petroleum refineries are required under the rule to keep track of all non-crude feedstocks that enter the refinery there should not be any double counting. If CTL products are imported either they will go straight to the market place or to a refinery for upgrading. In either case there will be little possibility of double counting.